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Analysis

On the causal dynamics between emissions, nuclear energy, renewable energy, and economic growth☆

Nicholas Apergis [a], James E. Payne [b,*], Kojo Menyah [c], Yemane Wolde-Rufael [d]

[a] Department of Banking and Financial Management, University of Piraeus, Karaoli and Dimitriou 80, Piraeus, ATTIKI 18534, Greece
[b] Department of Economics, Illinois State University, Normal, IL 61790-4200, United States
[c] London Metropolitan Business School, London Metropolitan University, 84 Moorgate, London, EC2M 6SQ, United Kingdom
[d] 135 Carnwath Road, London SW6 3HR, UK

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ABSTRACT

This paper examines the causal relationship between CO_2 emissions, nuclear energy consumption, renewable energy consumption, and economic growth for a group of 19 developed and developing countries for the period 1984–2007 using a panel error correction model. The long-run estimates indicate that there is a statistically significant negative association between nuclear energy consumption and emissions, but a statistically significant positive relationship between emissions and renewable energy consumption. The results from the panel Granger causality tests suggest that in the short-run nuclear energy consumption plays an important role in reducing CO_2 emissions whereas renewable energy consumption does not contribute to reductions in emissions. This may be due to the lack of adequate storage technology to overcome intermittent supply problems as a result electricity producers have to rely on emission generating energy sources to meet peak load demand.

1. Introduction

In the last few years many countries have been confronted with the challenge of producing more energy to meet their growing energy demand while at the same time grappling with the issue of reducing greenhouse gas emissions. It is generally believed that unless dramatic actions are taken to reduce global warming, the world could face an environmental catastrophe (Stern, 2007; Adamantiades and Kessides, 2009; DeCanio, 2009; Reddy and Assenza, 2009). The International Energy Agency (IEA, 2003, 2009a) suggests that current trends in energy supply and use are patently unsustainable — economically, environmentally and socially. Without decisive action, energy-related emissions of CO_2 will more than double by 2050 and increased oil demand will heighten concerns over the security of supplies (IEA, 2009a). Nobuo Tanaka, Executive Director, IEA, 2009b, emphasized this prognosis as follows: "The message is simple and stark: if the world continues on the basis of today's energy and climate policies, the consequences of climate change will be severe. Energy is at the heart of the problem — and so must form the core of the solution." Hence, the analysis so far suggests that continuing along today's energy path, without change in government policy by the major energy consuming countries would mean rapidly increasing dependency on fossil fuels, with alarming consequences for climate change.

The energy security problem facing energy-importing countries is equally daunting (Hedenus et al., 2010). The concentration of energy sources in the volatile region of the Middle East involves risks for many countries in terms of the reliability of the supply of energy (Gnansounou, 2008). Energy security and environmental challenges are forcing many countries to find energy alternatives to fossil fuels. Both renewable and nuclear energy sources are believed to provide some solutions to the problems of energy security and environmental degradation. Consequently, many countries have made investments in nuclear and renewable energy as a means to reduce dependence on imported oil, increase the supply of secure energy, minimize the price volatility associated with imported fossil fuels, and reduce greenhouse gas emissions (Toth and Rogner, 2006; Vaillancourt et al., 2008; Adamantiades and Kessides, 2009). Many believe that both nuclear and renewable energy, as virtually carbon free energy sources, could provide a major solution to global warming and energy security issues (Elliott, 2007; Ferguson, 2007). Even countries weary about the use of nuclear energy are now showing an interest in developing nuclear energy in order to diversify energy supplies, improve energy security, and provide a low-carbon energy alternative to fossil fuels (IEA, 2008; Adamantiades and Kessides, 2009).

While the increasing threat of global warming and climate change have drawn attention to the relationship between economic growth and environmental pollutants, research that looks into the impact of

☆ The authors appreciate the comments of the editor and referees.
* Corresponding author. Tel.: +1 309 438 5669.
E-mail addresses: napergis@unipi.gr (N. Apergis), jepayne@ilstu.edu (J.E. Payne), k.menyah@londonmet.ac.uk (K. Menyah), ywolde@gmail.com (Y. Wolde-Rufael).

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nuclear and renewable energy as possible panacea for emission reductions has been conspicuous by its absence. To date, empirical research has focused on investigating the causal relationship between energy consumption and economic growth, on the one hand, and between energy consumption and pollutant emissions on the other (Coondoo and Dinda, 2002; Dinda, 2004; Soytas et al., 2007; Chontanawat et al., 2008; Aslanidis and Iranzo, 2009; Apergis and Payne, 2009, 2010a); Sadorsky, 2009a; Sari and Soytas, 2009; Soytas and Sari, 2009; Ozturk, 2010; Payne, 2009, 2010a,b). There is a dearth of empirical research that looks into the causal relationship between nuclear energy consumption, renewable energy consumption, and CO_2 emissions using modern advances in time series econometrics associated with causality testing. The purpose of this study is to fill this gap by investigating the causal link between nuclear energy consumption, renewable energy consumption, CO_2 emissions, and economic growth for a group of 19 developed and developing countries for the period 1984–2007 within a panel error correction model framework. The main reason for studying the relationship between carbon emissions, nuclear energy and renewable energy is that both nuclear and renewable energy play an important role in the current debate on environmental protection and sustainable development. To our knowledge, this is the first study to use a heterogeneous panel error correction model to explore the causal relationships between nuclear and renewable energy consumption, CO_2 emissions, and economic growth. This allows us to draw conclusions from the analysis which may be applicable to a broad range of countries. This is important in light of the fact that there is a global effort to find ways of reducing emissions and the role of various energy sources in helping to achieve such an objective.

In the light of the discussion above, the rest of the study is organized as follows. Section 2 briefly discusses the potential role of nuclear and renewable energy in mitigating emissions. Section 3 describes the data and methodology along with the empirical evidence. Concluding remarks are presented in Section 4.

2. Potential Role of Nuclear and Renewable Energy in Mitigating CO_2 Emissions

Nuclear energy plays an important role not only in meeting the energy needs of many countries, but also in mitigating emissions. According to Adamantiades and Kessides (2009) the worldwide operation of nuclear plants makes a significant contribution to the mitigation of greenhouse gas emissions where nuclear plants currently save some 10% of CO_2 emissions from world energy use. Nuclear power plants have played a major role in reducing the amount of greenhouse gas emissions produced by the electricity sector in OECD countries (Nuclear Energy Agency, 2002). Furthermore, it is claimed that without nuclear power, OECD power plant carbon dioxide emissions would have been about one-third higher. Moreover, the European Union (2006) argues that Europe would not have been able to make any significant impact on reducing CO_2 emissions without the use of nuclear energy.

Like nuclear energy, renewable energy offers significant opportunities for further growth that can facilitate the transition to a global sustainable energy supply by the middle of this century (IEA, 2009a). In 2004, renewable energy accounted for 13.1% of world total primary energy supply. The use of non-hydro emerging renewable energy sources (wind, solar, geothermal, tidal, wave, and bio-energy) exhibits the fastest rate of increase, with most of the increase in power generation. The share of non-hydro renewable energy in total power output is expected to rise from 2.5% in 2007 to 8.6% in 2030, with wind power having the largest absolute increase (IEA, 2009a). According to the most optimistic scenario created by the IEA, by 2050, the share of renewable energy in the electricity generation mix could increase from 18% in 2004 to 39% by 2050. Renewable energy also serves a vital role in the global 50% CO_2 reduction target by 2050 if the long-term mean global temperature rise is to be limited to between 2 and 2.4 °C (IEA, 2009a). In contrast, nuclear energy is envisaged to contribute to only 6% of the global CO_2 reduction target by 2050. This is largely due to long lead times, high capital costs and public opposition to nuclear power in some countries. Nevertheless, both nuclear and renewable energy can potentially play a pivotal role not only in energy supplies, but also in emission reductions.

3. Data, Methodology, and Results

Annual data from 1984 to 2007 was obtained from the *World Bank Development Indicators*, CD-ROM and the *Energy Information Administration* for Argentina, Belgium, Brazil, Bulgaria, Canada, Finland, France, Hungary, India, Japan, Netherlands, Pakistan, South Africa, South Korea, Spain, Sweden, Switzerland, U.K., and the U.S. The multivariate framework for the analysis includes real GDP (Y) in billions of constant 2000 U.S. dollars, nuclear electricity net consumption (N) in millions of kilowatt hours, total renewable electricity net consumption (R) in millions of kilowatt hours, and total carbon dioxide emissions (E) from energy consumption in millions of metric tons.

The analysis begins with the examination of the stationarity properties of the variables by employing a battery of panel unit root tests.[1] Levin et al. (2002) propose a panel based ADF test with homogeneity in the dynamics of the autoregressive coefficients for all panel units with cross-sectional independence. The Im et al. (2003) panel unit root test differs from Levin et al. (2002) by allowing for heterogeneity in the dynamics of the autoregressive coefficients for all panel units. Finally, the nonparametric panel unit root tests of Maddala and Wu (1999) which combine the p-values from individual unit root tests are estimated using the Fisher–ADF and Fisher–PP tests. For each panel unit root test the null hypothesis is a unit root while the alternative hypothesis is no unit root. Table 1 displays the results of the panel unit root tests which indicate that each variable is integrated of order one.

To determine whether the variables are cointegrated, the Larsson et al. (2001, hereafter LLL) procedure is employed. The LLL(2001) procedure parallels the Johansen (1988) methodology within a panel error correction model framework and offers several advantages over residual-based cointegration tests. First, the LLL (2001) procedure allows for more than one cointegrating vector unlike, for instance, Pedroni (1999, 2004) which assumes there is only one cointegrating vector. Second, using the LLL (2001) method, no choice has to be made with respect to the normalization of variables. Finally, while the cointegrating relations are restricted to each cross-section, the rest of the model is unrestricted which allows for short-run dependence between the groups, the most appealing of which is that of cross-sectional dependence of the error terms.

To begin the analysis one must determine whether the Π matrix is of reduced rank and whether all N groups can each be characterized by r cointegrating vectors. If cointegration is found, the next step is to determine whether or not the cointegrating vectors are homogeneous. LLL (2001) consider testing for cointegration under the assumption that $\Pi_i = \alpha_i \beta_i' = \alpha\beta' = \Pi$ for $i = 1, \ldots, N$. The null hypothesis of the LLL test is $H_0{:}rk(\Pi_i) = k$ for $i = 1, \ldots, N$ against the alternative hypothesis that $H_1{:}rk(\Pi_i) = m$ for a non-vanishing fraction of cross-section members. This test statistic is similar to that of Im et al. (2003) and is given by a centered and scaled version of the cross-sectional average of the individual trace statistics. $LR_i^s(k|m)$ denotes the trace statistic for the null hypothesis of a k-dimensional cointegrating space for unit i where the superscript s indicates the specification of the deterministic components. Using the central limit

[1] To conserve space, the details of the panel unit root and stationarity tests have been omitted.